1. INTRODUCTION

1.1. Levels and trends in water quality

The quality of the Galveston Bay system has been of concern to citizens of the region and of Texas for at least 150 years. In 1841, the City of Houston passed an ordinance prohibiting the accumulation of sawdust on the shoreline of Buffalo Bayou, from lumber milling operations, due to the sawdust being washed into the stream (Sibley, 1968). This was an obvious cause-and-effect link to pollution of the watercourse. As the periphery and the watershed of Galveston Bay have developed, the effects of man's activities have become much more subtle and difficult to identify.

"It is a common thing for fishermen on the coast to remark that times are not what they used to be when phenomenal catches were made," (TGFOC, 1929) and the vacillations of the fishery have long been associated with the perception of pollution, or perhaps *vice versa*. In 1928, the annual report of the Texas Game, Fish & Oyster Commission states (quoting a *Houston Post-Dispatch* article comparing Galveston Bay around 1920 with its current state), "Fishing in the ship channel was ruined, and most of the marine life had been driven from the upper portions of the bay. Bathers often received generous coatings of oil. ...Today the ship channel is virtually free of oil pollution, and the bay once more teems with aquatic life. The 1928 fishing season in salt water areas below Houston has been the best season of the past ten years." (TGFOC, 1928.) In 1935, "Refineries on the Ship Channel discharge their effluents into the channel, but it is usually clean. The oil is trapped and the acids treated. Fishing up the channel from Galveston is said to be improving." (TGFOC, 1935.) The late 1930's and early 40's received a sequence of natural catastrophes, from floods (1935-36) and hurricanes (1942) to extreme freezes (1939-40) and drought (1943-45). The annual report of 1946 notes a sharp decline in the fishery and states, "The total catch from the Galveston area is an insignificant per cent of the total production in Texas waters and can be expected to remain so until the heavy industrial pollution of that region is abated." (TFGOC, 1946.)

While occasionally other types and sources of pollution were identified in the first half of the century, such as an outbreak of shellfish poisoning in 1944 due to sewage contamination of the lower reefs (Wise et al., 1944, 1948) and extensive bayshore contamination in 1950 by sanitary discharges in the upper bay (Metyko, 1952), the focus was (appropriately) on the Houston Ship Channel, and specifically the discharge of oil. Again, most of the surviving information is anecdotal. TGFOC (1928) reported on a clean-up campaign in the Channel area to reduce waste oil, which posed "a grave fire hazard" and the same *Houston Post-Dispatch* article noted that around 1910 "the Houston ship channel was smeared with oil and other destructive ingredients, from the foot of Main street to Morgan's Point, while oil covered large portions of the bay." Interestingly, even this early in the century, the idea had been floated to give up the Channel to the "uses of commerce" (TGFOC, 1928), a suggestion that has continued to emerge due to the

difficulty of reconciling water quality goals with the intensive industrial-municipal activities (most recently as the "Hann Plan" of Dr. Roy Hann at Texas A&M). While the problem of Ship Channel pollution may have been reduced by 1928, it certainly had not been eliminated. In 1933, it was noted that, "The oil refineries on the ship channel are making an honest effort to take care of their waste and are usually very clean.... Complaints reach the department at intervals about oil on the bay at Galveston, but it appears that this pollution is from inbound ships rather than from refineries and oil fields inland." (TGFOC, 1933.) To the present, the Houston Ship Channel has continued to receive the focus of concern in Galveston Bay. Since 1970, it has been described as "the most-polluted body of water in the U.S." (e.g. Eckhardt, 1971) and a "water-quality success story" (EPA, 1980).

There may have been other physico-chemical alterations in Galveston Bay throughout the century as well, but again the bulk of the evidence is anecdotal and the extent of anthropogenic involvement is unclear. An interesting example is the oyster drill, which has become a major concern in recent years due to its potential proliferation should bay salinities increase. The first significant note on drill activity in Galveston Bay in the reports of TGFOC occurs in 1935, in which the damage to oysters of heavy freshwater inflows in that year are weighed against the destruction of drills "which have been active in portions of East and West Bays" (TGFOC, 1935). The next mention is twenty years later (TGFOC, 1954), when "A very limited invasion of the conch (Thais) occurred in portions of Red Fish Bar due to an increase in the salinity of the water. No live conchs were found in this portion of the bay but their presence was shown by egg cases. This predator has not yet assumed an important role in Galveston Bay." This statement must be tempered by the fact that monitoring of Galveston oyster beds by a marine biologist of TGFOC had only begun in 1951. In another decade, conch predation was labeled a "serious problem" (TGFC, 1961) though the report does not indicate the geographical extent of predation. Later, TGFC (1963) reports, "Predation by the conch increased in the lower bay, but the conch did not extend its range upward into the middle bay area." One would infer from these reports that drill predation is a recent and increasing problem in Galveston Bay. This is belied by other sources, and illustrates the dangers of relying upon anecdotal evidence. For example, Galtsoff (1931) notes, "Oysters collected in this bay [West Bay] were of the coon type, but many reefs, as for example, Karankawa Reef, contained nothing but dead shells. The oysters were said to have been destroyed two years ago by the conch. ... The reef opposite Texas City [Half Moon Reef] produces good marketable oysters. The grounds are, however, badly infested by the conch. ... The abundance of the conch is due to the high salinity of the water in this section of the bay. ... Possibly in a few years the valuable oyster beds of this section will be destroyed, as has happened on Karankawa Reef in West Bay."

The above types of qualitative, anecdotal information are interesting from a historical viewpoint, but do not contribute to answering the questions of whether significant problems in water quality presently exist in Galveston Bay and whether there is (or has been) a long-term alteration in water quality. Two elements are needed in order to appraise variation in water quality and to identify its cause. First is a quantitative measure, i.e. identification and analysis of a

parameter (or parameters) indicative of water quality, which in principle can provide time-space continuity. Reports of fish kills and bathers coated in oil are dramatic evidence of something, but offer little basis for scientific evaluation. The second is an extensive data base on the parameter with sufficient spatial and temporal resolution, and extending over a sufficient time period to separate trends from natural variability. This latter, of course, is the real obstacle.

Several notable attempts to establish the level of water-quality and the existence of trends in Galveston Bay exist in the literature. Gloyna and Malina (1964) conducted a comprehensive survey of water quality throughout the system by compiling all data available to them. They emphasized the spatial variation of quality within the season, and short-term fluctuations rather than long-term trends. At the close of the Texas State Department of Health Galveston Bay Project, TSDH (1968) summarized the status of the bay according to coliform and BOD levels as follows:

Area	*Rating (MPN)*	*Rating (BOD)*
Houston Ship Channel	Polluted	Polluted
Clear Lake	Poor	Poor
Trinity Bay	Excellent	Good
Upper Galveston Bay	Excellent	Good
Central Galveston Bay	Excellent	Good
Lower Galveston Bay	Excellent	Good
East Bay	Excellent	Excellent
West Bay	Excellent	Excellent

in which "excellent" means coliform MPN < 50/100mL and BOD < 2.5 mg/L, "good" means BOD < 5.0, "poor" means MPN < 1000 and BOD <7.5, and "polluted" means MPN > 1000 and BOD > 7.5. Further, statistical trend lines through these data showed a positive slope throughout the bay, evidencing a "continued degradation." This analysis covered the period 1963-67. In a report of very limited circulation, Texas Environmental Research Corporation (1968) presented a trends analysis of Trinity Bay based upon the U.S. Bureau of Commercial Fisheries (USBCF) and TSDH data, *which was inconclusive*.

In 1968, The Texas Water Quality Board initiated its ("The") Galveston Bay Project and midway through the program performed its own trends analysis (Espey et al., 1971b) of the main sections of the bay (i.e., exclusive of the Houston Ship Channel). This analysis extended the record for all of the TSDH stations which corresponded to GBP stations, to cover the period 1963-70. (Espey et al., 1971b, noted that the TSDH trends analysis used only two or three stations from each bay section, despite a much larger number of stations available, and intimated that the selection might have been deliberate to display a trend of degradation.) The increase in coliforms in lower Galveston Bay was confirmed. There were also increases in the Chocolate Bay area and in the eastern portion of West Bay, which were offset by decreases in middle West Bay. Otherwise, no significant change in coliforms or BOD was detected.

The most recent attempt is due to Stanley (1989), who combined data from four long-term data bases: TSDH, U.S. Bureau of Commercial Fisheries, Texas Water Commission and Galveston Bay Project. He compiled a time series of data back to the 1960's, and examined a different suite of parameters than those of the studies cited above, but, in order to keep the scope of his study manageable, limited the analysis to representative stations in the major segments of the bay. He examined temporal plots at these stations by eye for trends in nitrogen, phosphorus, and trace contaminants such as heavy metals. He noted an apparent decrease in nitrogen species, which he believes is more likely an artifact due to noncomparability of the measurements in different (non-overlapping) programs rather than a real decline. Substantial declines in all of these in the Houston Ship Channel were noted. He did not examine coliforms or BOD.

The above-cited trends studies all suffered from the same difficulty of attempting a statistical summary with a set of data that lacked either sufficient temporal or sufficient spatial scope to permit statistically meaningful inferences about existing water quality and temporal trends. Generally, any single data-collection program lacks the resources and longevity to develop a data base sufficiently comprehensive for analysis of water quality levels and trends in a system such as Galveston Bay. This is due to the extreme natural variability of most water-quality parameters. The best prospect for a definitive study is to begin with a synthesis of data from a number of programs, using the entire spatial and temporal scope of each program.

1.2 Objectives and prosecution of project

For many years, data relating to the quality of water and sediment have been collected in the Galveston Bay system by a variety of organizations and individuals. The objectives of data collection have been equally varied, including the movement and properties of water, the biology of the bay, waste discharges and their impacts, navigation, geology and coastal processes, and fisheries. While the specific purposes of the individual data collection projects have limited each project in time and space, the data have great potential value to the Galveston Bay National Estuary Program (GBNEP) if they can be combined into a comprehensive data base yielding a historical depiction of the quality of the bay environment.

The purpose of this project was to compile and evaluate these data, and to employ these data in a quantitative assessment of water and sediment quality of Galveston Bay and its evolution over time. There were several subordinate objectives in the project, as outlined in the following sections. However, the key objectives were threefold, *viz.*:

(1) compilation of a comprehensive data base in machine-manipulable format,

(2) analysis of time and space variation (including "trends") in quality parameters,

(3) identification of possible causal mechanisms to explicate the observed variations.

Securing these objectives will provide a foundation for further scientific study of Galveston Bay, for identifying and prioritizing specific problems affecting the quality of the Bay, for formulation and specification of future monitoring programs for the Bay, and for a general understanding of the controls and responses of Bay water quality, which must underlie rational management of the resources of the system.

This project was prosecuted according to the Work Plan (Ward and Armstrong, 1990), which in turn generally conformed to the outline of the draft Scope of Work prepared by GBNEP management. Two separate documents have been developed from this project, because there are two different aspects of the project that would benefit by independent reporting. The present report employs the data base to characterize the Galveston Bay system, including statistical analyses of the data for key water-quality areas and all TWC segments, identification of water-quality problems, and an analysis of apparent mechanisms for the variation in space and time of water quality, and for the occurrence of water-quality problems. This report includes the rationale and formulation of the aggregated data base, including the specification of the water-quality areas. This report also includes an assessment of the historical data base and the data collection programs that have produced it, with gaps and inadequacies identified, and specific recommendations for future monitoring programs in Galveston Bay. A companion report (Ward and Armstrong, 1992) addresses the data base itself, documenting the sources for the data, formatting of the data, methodology, quality, and spatio-temporal coverage. This report should function as a Users Guide to the data base, to form the foundation for use of the data base by other researchers.

The focus of this study was on the quality of water and sediments in the Galveston Bay system. "Quality" is a broad term, referring in general to any quantitative parameter (or suite of parameters, taken collectively) that can serve as an *indicator* for a potential use of water in Galveston Bay. "Use" in this context means "function" and includes the uses of nature as well as the activities of man. By this definition, "quality" would range from physical properties such as current velocity to organisms of the bay, and would include the atmospheric and terrestrial environs. We adopted a narrower definition, consistent with the draft Scope of Work and with the other projects within the GBNEP that are examining other components of Galveston Bay, that "quality" is defined by physical, chemical and microbiological constituents associated with the Bay waters or its suspensions.

This project sought data from various sources, relating to the general categories of parameters listed in Table 1-1, and created a computer-manipulable data base. Generally, the first portion of the project effort concentrated upon acquisition and transmittal of data holdings, and the latter portion with data entry, and the development of the data base. This project relied upon and built from the work accomplished in the previous GBNEP Data Inventory Project. The Data Inventory

TABLE 1-1

General categories of water/sediment quality parameters addressed in project
(See Chapter 3 for detailed parameter listings)

Indicator variables (bacteriological and chemical)
Nutrients (carbon, phosphorus and nitrogen)
Heavy metals
Pesticides
Priority pollutants
Organics
Suspended matter
Physical indicators, including density and dissolved solids

Project was extremely useful in having identified major historical programs and probable locations of surviving data. The task of recovering historical data sets from oblivion was continued in the present program, and one major product of this project is consistent, digital forms of the major water/sediment programs from the Bay.

The suite of parameters examined (detailed in Chapter 3) is a combination of those identified in the Draft Scope of Work from GBNEP and added by the Principal Investigators in the Work Plan (Ward and Armstrong, 1990). Our philosophy in recommending these additions is that at the time of data acquisition and transfer, the inclusion of a few additional variables is of no consequence from a cost or labor point of view, compared to having to return later for a second retrieval, and some of these variables may prove invaluable in the analysis effort. One of the added parameters was the Biochemical Oxygen Demand (BOD). While there are well-known weaknesses and ambiguities in the classical BOD test, the BOD is probably the only indicator of organic loading for which there is the potential of a long-term record of data in Galveston Bay, hence our recommendation to include it. Another added parameter was oil and grease. Oil and grease is a spongy variable, easily corrupted by local influences, imprecise, and sensitive to details of analytical methodology. It also measures a variable different from its name—a continuing source of obfuscation. But there is a fairly good long-term record in the data and, given the present concern of hydrocarbon impacts in the Galveston Bay system, was considered worth including in the data base. Another added parameter was volatile solids, a general, rough measure for organics, especially useful in judging contamination of sediments, which, like BOD, may offer the best prospect for a long-term period of record. Grain-size of sediments was also added because it is an important indicator of sediment texture and can be crucial in assigning partitioning coefficients, but our intentions were frustrated with this variable due the paucity of measurements.

One of the major difficulties noted in the previous Data Inventory Project (Ward and Armstrong, 1991) was the poor response from many of the major agencies

responsible for historical data collection in Galveston Bay. That project, Data Inventory, was concerned with locating and inventorying the data, while this project, Water Quality Status and Trends, was concerned with the actual acquisition of data. As might be anticipated, we encountered the same problem of poor response again. Time periods of months were required to obtain digital copies of data bases; in one instance ten months elapsed between our (first) request and our eventual receipt of the data. This difficulty was compounded by several inaccurately filled requests, where we received only part of the data base, and had to request additional data retrievals. There is an important difference between the present project and the previous Data Inventory Project in the consequences of this poor response. In the previous project, poor response was an inconvenience, but we could proceed with the work on other data sets without the response from pending requests. In the present status and trends analysis, it is imperative that all data be on hand before we begin the analytical aspect of the work; otherwise much of the analysis would have to be repeated. This poor response therefore directly translated to scheduling problems. (Clearly, a ten-month delay in receipt of data in a project in which the draft report is due in ten months is a calamity.)

Many of the data sets employed in this study exist only in a limited number of hard copies. A major part of the effort of this project was invested in keyboarding this data to create a digital data base. This keyboarding process was delayed by the same problem of poor response, as well as the time necessary in some instances to physically locate the data. The problems of acquiring such data sets would be a formidable obstacle to any future researcher's compiling an adequate data base for Galveston Bay. Therefore, we regard the synthesized digital data base as a major product of the project as it allows future researchers much greater scope in analysis than could be afforded by the data sets normally available to individual scientists.

Procedures of data processing are described in Chapters 2-4, the analyzed water and sediment quality data are presented in Chapters 5 and 6, respectively, the possible cause-and-effect processes suggested by associations in the data are discussed in Chapter 7, and a summary of conclusions and list of recommendations are given in Chapter 8. The core of the report is considered to be Chapters 5 and 6. Our philosophy is to present the *facts* of the data in these chapters, reserving the *interpretation* of the data for Chapters 7 and 8. The interpretations postulate conceptual models and may be biased by the predilections of these investigators. Certainly, they will be subject to revision upon additional data collection or more sophisticated analyses. However, the results of Chapters 5 and 6 should stand as *facts*, circumscribed only by the statistical measures selected, criteria for rejection or weighting, and the assumed proxy relationships (where used).

page 24
Blank